

# Chapter 5

## Experimental results

The experimental values of total attenuation cross sections of all the amino acid and sugar compounds used in the study (Table 5.4 to 5.25), for all the energies of interest are compared with theoretical values of Hubbell (1982) and XCOM the PC based data base of Berger & Hubbell (1987). The theoretical values of amino acids and sugars were suitably calculated with the aid of *the mixture rule* and interpolated to the energies of interest from the tabulated cross sections of Hubbell (1982) for the elements Hydrogen, Carbon, Nitrogen Oxygen and Sulphur (Table 5.1)

According to mixture rule

$$\frac{\mu}{\rho} = \sum_i w_i \left( \frac{\mu}{\rho} \right)_i \quad (5.1)$$

where  $(\mu/\rho)_i$  is the mass attenuation coefficient of the  $i^{th}$  element and  $w_i$  its proportion by weight,

The limitation of the mixture rule is that it treats the complex medium under consideration as a *mixture* of various atomic constituents. Thus *it does not account for any variation in the atomic wave functions, which occur due to changes in the molecular, chemical or crystalline environment of an atom.* This in fact may seriously affect the accuracy of the results obtained by the application of the mixture rule. *This is true*

*only when the incident photon energy is in the vicinity of the edge energies* of the constituent elements of the compound [Hubbell (1969), Jackson and Hawkes (1981), Jackson (1982), Kerur et al. (1992a,b)]. In all other cases the error is less than 1%. So the error in the theoretical values of total attenuation cross sections of sugar and amino acid compounds, derived from the total attenuation cross sections of their elements — Hydrogen, Nitrogen, Carbon, Oxygen and Sulphur, all of which are low *Z* elements — is considered negligible.

*As a further check* on the reliability of the experimental values of total attenuation cross sections, the measurements were carried out for 99.9 % pure foils of Aluminum and Copper (Tables 5.2 and 5.3). A good agreement was observed between the theoretical and experimentally obtained values of these elements. This increased confidence in the present measurements.

Table 5.1: Cross sections of elements H, C, N, O, S interpolated to the energies of interest, from Hubbell (1982)

Energy (keV)	$\sigma_H$	$\sigma_C$	$\sigma_N$	$\sigma_O$	$\sigma_S$
30.8	0.5975	4.99	6.98	9.83	103.15
35	0.5888	4.46	6.05	8.24	73.79
81	0.5145	3.23	3.72	4.28	13.25
145	0.4463	2.73	3.06	3.39	7.05
276.4	0.3642	2.19	2.56	2.94	6.07
302.9	0.3530	2.12	2.48	2.84	5.80
356	0.3319	1.99	2.33	2.67	5.38
383.9	0.3217	1.93	2.26	2.58	5.20
661.6	0.2566	1.54	1.79	2.05	4.10
1173	0.1955	1.17	1.37	1.57	3.14
1332.5	0.1829	1.10	1.28	1.47	2.98

Table 5.2: Total attenuation cross sections for Aluminum

Energy (keV)	Present value	Hubbell (1982)	XCOM
30.8	47.00	47.10	47.30
35	36.00	35.00	34.5
81	8.65	8.70	8.94
145	5.71	5.72	6.27
276.4	4.58	4.64	4.82
302.9	4.46	4.47	4.65
356	4.23	4.20	4.36
383.4	4.10	4.09	4.23
661.6	3.35	3.36	3.35
1173	2.52	2.53	2.54
1332.5	2.36	2.38	2.38

Table 5.3: Total attenuation cross sections for Copper

Energy (keV)	Present value	Hubbell (1982)	XCOM
30.8	1060.00	1076.00	1070.00
35	772.00	748.00	746.00
81	78.00	77.00	78.10
145	26.39	26.38	24.60
276.4	12.20	12.40	12.50
302.9	11.60	11.70	11.70
356	10.50	10.60	10.60
383.4	9.90	10.14	10.20
661.6	7.70	7.66	7.66
1173	5.75	5.74	5.73
1332.5	5.38	5.38	5.38

# **Total attenuation cross sections**

**of**

**Sugars**

(The experimental errors are to the extent of 2%)

Table 5.4: energy 30.8 keV

Total Attenuation Cross Sections of Sugars (b/molecule)

Name of the compound	Experimental value	Hubbell (1982)	XCOM
Arabinose	81.60	80.06	78.99
Ribose	82.20	80.06	78.99
Glucose	99.00	96.07	94.79
Galactose	98.60	96.07	94.79
Mannose	98.00	96.07	94.79
Fructose	98.40	96.07	94.79
Rhamnose	100.00	97.26	95.98
Maltose	188.00	181.10	178.98
Melibiose	186.20	181.10	178.98
Melezitose	285.00	277.00	274.03
Raffinose	320.00	321.30	316.65

Table 5.5: energy 35 keV

Total Attenuation Cross Sections of Sugars (b/molecule)

Name of the compound	Experimental value	Hubbell (1982)	XCOM
Arabinose	72.00	69.37	68.44
Ribose	71.60	69.37	68.44
Glucose	86.40	83.25	82.13
Galactose	87.00	83.25	82.13
Mannose	86.00	83.25	82.13
Fructose	86.60	83.25	82.13
Rhamnose	87.40	84.40	83.31
Maltose	164.00	157.10	155.40
Melibiose	165.00	157.10	155.40
Melezitose	250.00	240.30	237.26
Raffinose	284.00	278.00	274.11

Table 5.6: energy 81 keV

Total Attenuation Cross Sections of Sugars (b/molecule)

Name of the compound	Experimental value	Hubbell (1982)	XCOM
Arabinose	44.00	42.70	43.28
Ribose	43.60	42.70	43.28
Glucose	52.00	51.24	51.94
Galactose	52.40	51.24	51.94
Mannose	52.20	51.24	51.94
Fructose	51.40	51.24	51.94
Rhamnose	53.00	52.30	52.97
Maltose	99.00	97.17	98.49
Melibiose	100.00	97.17	98.49
Melezitose	151.40	148.40	150.43
Raifinose	172.00	170.00	171.97

Table 5.7: energy 145 keV

Total Attenuation Cross Sections of Sugars (b/molecule)

Name of the compound	Experimental value	Hubbell (1982)	XCOM
Arabinose	36.70	35.47	36.32
Ribose	36.76	35.47	36.32
Glucose	44.01	42.55	43.59
Galactose	44.00	42.55	43.59
Mannose	43.91	42.55	43.59
Fructose	43.85	42.55	43.59
Rhamnose	44.58	43.45	44.48
Maltose	83.60	80.65	82.64
Melibiose	83.59	80.65	82.64
Melezitose	127.44	123.29	126.22
Raffinose	144.94	140.89	144.36

Table 5.8: energy 276.4 keV

Total Attenuation Cross Sections of Sugars (b/molecule)

Name of the compound	Experimental value	Hubbell (1982)	XCOM
Arabinose	30.00	29.28	29.22
Ribose	29.60	29.28	29.22
Glucose	36.00	35.14	35.06
Galactose	36.40	35.14	35.06
Mannose	36.00	35.14	35.06
Fructose	36.10	35.14	35.06
Rhamnose	36.40	35.90	35.79
Maltose	68.00	66.61	66.48
Melibiose	68.80	66.61	66.48
Melezitose	104.00	101.75	101.54
Raffinose	119.00	116.40	116.14

Table 5.9: energy 302.9 keV

Total Attenuation Cross Sections of Sugars (b/molecule)

Name of the compound	Experimental value	Hubbell (1982)	XCOM
Arabinose	28.50	28.35	28.18
Ribose	28.20	28.35	28.18
Glucose	34.20	34.02	33.81
Galactose	34.00	34.02	33.81
Mannose	34.40	34.02	33.81
Fructose	34.20	34.02	33.81
Rhamnose	34.60	34.72	34.52
Maltose	65.00	64.50	64.11
Melibiose	64.00	64.50	64.11
Melezitose	98.20	98.51	97.92
Raffinose	113.00	112.70	112.01

Table 5.10: energy 356 keV

Total Attenuation Cross Sections of Sugars (b/molecule)

Name of the compound	Experimental value	Hubbell (1982)	XCOM
Arabinose	27.00	26.61	26.57
Ribose	27.20	26.61	26.57
Glucose	32.50	31.94	31.89
Galactose	33.00	31.94	31.89
Mannose	32.60	31.94	31.89
Fructose	32.70	31.94	31.89
Rhamnose	33.00	32.60	32.55
Maltose	61.60	60.54	60.45
Melibiose	62.00	60.54	60.45
Melezitose	94.00	92.50	92.35
Raffinose	107.00	105.80	105.62

Table 5.11: energy 383.9 keV

Total Attenuation Cross Sections of Sugars (b/molecule)

Name of the compound	Experimental value	Hubbell (1982)	XCOM
Arabinose	26.40	25.78	25.82
Ribose	26.00	25.78	25.82
Glucose	32.00	30.94	30.98
Galactose	31.80	30.94	30.98
Mannose	32.10	30.94	30.98
Fructose	32.00	30.94	30.98
Rhamnose	32.20	31.60	31.63
Maltose	61.20	58.65	58.69
Melibiose	61.00	58.65	58.69
Melezitose	92.00	89.59	89.65
Raffinose	105.00	102.50	102.62

Table 5.12: energy 661.6 keV

Total Attenuation Cross Sections of Sugars (b/molecule)

Name of the compound	Experimental value	Hubbell (1982)	XCOM
Arabinose	20.27	20.51	20.52
Ribose	20.30	20.51	20.52
Glucose	24.32	24.61	24.62
Galactose	24.30	24.61	24.62
Mannose	24.34	24.61	24.62
Fructose	24.28	24.61	24.62
Rhamnose	24.60	25.12	25.13
Maltose	46.20	46.65	46.68
Melibiose	46.70	46.65	46.68
Melezitose	70.50	71.26	71.30
Raffinose	80.20	81.51	81.56

Table 5.13: energy 1173 keV

Total Attenuation Cross Sections of Sugars (b/molecule)

Name of the compound	Experimental value	Hubbell (1982)	XCOM
Arabinose	16.00	15.66	15.63
Ribose	16.10	15.66	15.63
Glucose	19.08	18.79	18.75
Galactose	18.88	18.79	18.75
Mannose	18.80	18.79	18.75
Fructose	19.20	18.79	18.75
Rhamnose	19.60	19.18	19.14
Maltose	36.30	35.62	35.56
Melibiose	36.00	35.62	35.56
Melezitose	55.40	54.40	54.31
Raffinose	63.00	62.23	62.12

Table 5.14: energy 1332.5 keV

Total Attenuation Cross Sections of Sugars (b/molecule)

Name of the compound	Experimental value	Hubbell (1982)	XCOM
Arabinose	15.00	14.67	14.64
Ribose	15.00	14.67	14.64
Glucose	18.10	17.61	17.57
Galactose	17.80	17.61	17.57
Mannose	17.95	17.61	17.57
Fructose	18.11	17.61	17.57
Rhamnose	18.24	17.97	17.94
Maltose	34.40	33.38	33.31
Melibiose	34.20	33.38	33.31
Melezitose	52.30	50.99	50.88
RafEnose	59.50	58.33	58.20

# **Total attenuation cross sections**

**of**

**Amino acids**

(The experimental errors are to the extent of 2%)

Table 5.15: energy: 30.8 keV

Total Attenuation Cross Sections of Amino Acids (b/molecule)

Name of the compound	Experimental value	Hubbell (1982)	XCOM
Glycine	40.00	39.60	39.15
Alanine	47.50	45.80	45.32
Serine	56.40	55.60	54.97
Valine	60.40	58.14	57.64
Threonine	63.80	61.80	61.11
Leucine	66.50	64.32	63.84
Isoleucine	66.00	64.32	63.84
Aspartic Acid	71.00	70.42	69.48
Lysine	73.00	71.90	71.30
Glutamic Acid	78.40	76.60	75.75
Histidine	79.00	75.90	75.23
Phenyl Alanine	80.40	78.08	77.70
Arginine	89.00	85.85	85.18
Tyrosine	90.50	87.91	87.34
Tryptophan	99.00	95.63	95.22
Cysteine	303.00	296.70	298.56

Table 5.16: energy: 35 keV

Total Attenuation Cross Sections of Amino Acids (b/molecule)

Name of the compound	Experimental value	Hubbell (1982)	XCOM
Glycine	35.00	34.40	33.99
Alanine	41.40	40.03	39.67
Serine	48.90	48.26	47.75
Valine	52.40	51.30	51.03
Threonine	55.37	53.90	53.54
Leucine	58.90	56.94	56.67
Isoleucine	59.00	56.94	56.67
Aspartic Acid	61.80	60.96	60.21
Lysine	63.00	63.58	63.29
Glutamic Acid	68.40	66.60	65.82
Histidine	69.20	66.70	66.42
Phenyl Alanine	70.80	69.15	68.91
Arginine	78.00	75.68	75.23
Tyrosine	79.20	77.38	77.08
Tryptophan	86.00	84.77	84.59

Table 5.17: energy 81 keV

Total Attenuation Cross Sections of Amino Acids (b/molecule)

Name of the compound	Experimental value	Hubbell (1982)	XCOM
Glycine	21.70	21.30	21.64
Alanine	25.70	25.28	25.94
Serine	30.36	29.85	30.30
Valine	33.80	34.10	34.36
Threonine	34.40	34.11	34.76
Leucine	38.10	38.90	38.64
Isoleucine	37.90	38.90	38.04
Aspartic Acid	38.45	37.37	37.92
Lysine	42.20	42.59	42.97
Glutamic Acid	42.50	41.63	42.22
Histidine	44.84	43.74	44.17
Phenyl Alanine	47.70	47.00	47.11
Arginine	50.33	50.30	50.53
Tyrosine	52.40	51.30	51.70
Tryptophan	58.00	57.72	57.85
Cysteine	79.00	76.62	77.79

Table 5.18: energy 145 keV

Total Attenuation Cross Sections of Amino Acids (b/molecule)

Name of the compound	Experimental value	Hubbell (1982}	XCOM
Glycine	18.42	17.71	18.16
Alanine	21.85	21.60	21.79
Serine	25.76	24.81	25.42
Valine	28.69	28.51	29.04
Threonine	29.19	28.40	29.05
Leucine	32.10	32.32	32.66
Isoleucine	32.13	32.32	32.66
Aspartic Acid	32.00	31.02	31.80
Lysine	35.80	35.66	34.06
Glutamic Acid	36.02	34.62	35.42
His ti dine	37.99	36.51	37.25
Phenyl Alanine	40.43	39.27	40.46
Arginine	42.63	41.91	42.66
Tyrosine	44.34	42.77	43.60
Tryptophan	49.95	48.25	48.74
Cysteine	58.72	56.85	58.78

Table 5.19: energy 276.4 keV

Total Attenuation Cross Sections of Amino Acids (b/molecule)

Name of the compound	Experimental value	Hubbell (1982)	XCOM
Glycine	14.34	14.64	14.61
Alanine	17.61	17.56	17.53
Serine	20.07	20.50	20.45
Valine	22.90	23.40	23.38
Threonine	22.74	23.42	23.49
Leucine	25.40	26.32	26.30
Isoleucine	25.40	26.32	26.30
Aspartic Acid	25.41	25.62	25.57
Lysine	29.92	29.25	29.22
Glutamic Acid	28.10	28.52	28.49
Histidine	29.63	30.00	29.96
Phenyl Alanine	31.54	32.17	32.15
Arginine	33.26	34.37	34.34
Tyrosine	34.60	35.10	35.07
Tryptophan	39.02	39.48	39.46
Cysteine	45.86	46.53	46.43

Table 5.20: energy 302.9 keV

Total Attenuation Cross Sections of Amino Acids (b /molecule)

Name of the compound	Experimental value	Hubbell (1982)	XCOM
Glycine	14.00	14.17	14.09
Alanine	16.88	17.00	16.91
Serine	19.44	19.84	19.73
Valine	21.79	22.66	22.55
Threonine	22.01	22.67	22.54
Leucine	24.91	25.49	25.37
Isoleucine	24.27	25.49	25.37
Aspartic Acid	24.60	24.81	24.66
Lysine	28.00	28.33	28.19
Glutamic Acid	27.20	27.64	27.48
Histidine	28.70	29.04	28.89
Phenyl Alanine	30.60	31.16	31.00
Arginine	32.90	33.29	33.12
Tyrosine	33.50	34.00	33.82
Tryptophan	37.80	38.24	38.05
Cysteine	44.43	44.90	44.78

Table 5.21: energy 356 keV

Total Attenuation Cross Sections of Amino Acids (b/molecule)

Name of the compound	Experimental value	Hubbell (1982)	XCOM
Glycine	13.14	13.30	13.29
Alanine	15.80	15.96	15.94
Serine	18.40	18.63	18.60
Valine	20.69	21.28	21.26
Threonine	20.83	21.29	21.26
Leucine	23.96	23.94	23.92
Isoleucine	23.60	23.94	23.92
Aspartic Acid	23.30	23.29	23.25
Lysine	25.90	26.60	26.58
Glutamic Acid	25.74	25.95	25.91
Histidine	27.16	27.27	27.24
Phenyl Alanine	28.90	29.26	29.24
Arginine	30.50	31.26	31.23
Tyrosine	31.80	31.92	31.90
Tryptophan	35.74	35.91	35.88
Cysteine	42.40	42.03	41.87

Table 5.22: energy 383.9 keV

Total Attenuation Cross Sections of Ammo Acids (b/molecule)

Name of the compound	Experimental value	Hubbell (1982)	XCOM
Glycine	12.80	12.90	12.90
Alanine	15.05	14.80	15.48
Serine	17.87	18.04	18.06
Valine	19.90	20.62	20.64
Threonine	20.75	20.62	20.64
Leucine	23.13	23.20	23.22
Isoleucine	23.31	23.20	23.22
Aspartic Acid	22.60	22.56	22.60
Lysine	25.06	25.77	25.80
Glutamic Acid	25.00	25.14	25.15
Histidine	26.30	26.42	26.45
Phenyl Alanine	28.10	28.35	28.38
Arginine	29.62	30.29	30.31
Tyrosine	30.80	30.93	30.96
Tryptophan	34.74	34.79	34.84
Cysteine	40.84	40.69	40.81

Table 5.23: energy 661.6 keV

Total Attenuation Cross Sections of Amino Acids (b/molecule)

Name of the compound	Experimental value	Hubbell (1982)	XCOM
Glycine	10.22	10.25	10.26
Alanine	12.23	12.30	12.31
Serine	14.31	14.35	14.36
Valine	16.20	16.41	16.42
Threonine	16.20	16.41	16.42
Leucine	18.26	18.46	18.47
Isoleucine	17.90	18.46	18.47
Aspartic Acid	18.10	17.94	17.95
Lysine	19.90	20.51	20.52
Glutamic Acid	20.00	19.99	20.01
Histidine	21.13	21.02	21.03
Phenyl Alanine	22.50	22.56	22.58
Arginine	23.70	24.10	24.11
Tyrosine	24.67	24.52	24.63
Tryptophan	27.80	27.69	27.70
Cysteine	32.70	32.30	32.37

Table 5.24: energy 1173 keV

Total Attenuation Cross Sections of Amino Acids (b/molecule)

Name of the compound	Experimental value	Hubbell (1982)	XCOM
Glycine	7.88	7.83	7.81
Alanine	9.50	9.39	9.38
Serine	11.17	10.96	10.94
Valine	12.44	12.52	12.50
Threonine	12.66	12.51	12.50
Leucine	14.07	14.09	14.07
Isoleucine	13.94	14.09	14.07
Aspartic Acid	14.04	13.70	13.67
Lysine	15.54	15.65	15.63
Glutamic Acid	15.63	15.26	15.24
Histidine	16.50	16.05	16.02
Phenyl Alanine	17.55	17.22	17.20
Arginine	18.51	18.39	18.37
Tyrosine	19.05	18.78	18.76
Tryptophan	21.30	21.13	21.10
Cysteine	25.52	24.67	24.62

Table 5.25: energy 1332.5 keV

Total Attenuation Cross Sections of Amino Acids (b/molecule)

Name of the compound	Experimental value	Hubbell (1982)	XCOM
Glycine	7.34	7.34	7.32
Alanine	8.85	8.80	8.79
Serine	10.55	10.27	10.25
Valine	11.70	11.73	11.71
Threonine	11.95	11.74	11.72
Leucine	13.20	13.20	13.18
Isoleucine	13.18	13.20	13.18
Aspartic Acid	13.06	12.84	12.81
Lysine	14.70	14.67	14.65
Glutamic Acid	14.60	14.31	14.28
Histidine	15.20	15.04	15.01
Phenyl Alanine	16.60	16.13	16.11
Arginine	17.50	17.23	17.21
Tyrosine	18.00	17.60	17.57
Tryptophan	20.00	19.80	19.77
Cysteine	23.80	23.20	23.07